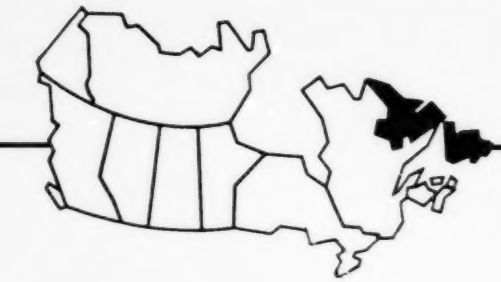
Government of Canada | Gouvernement du Canada
Canadian Forestry Service | Service canadien des forêts

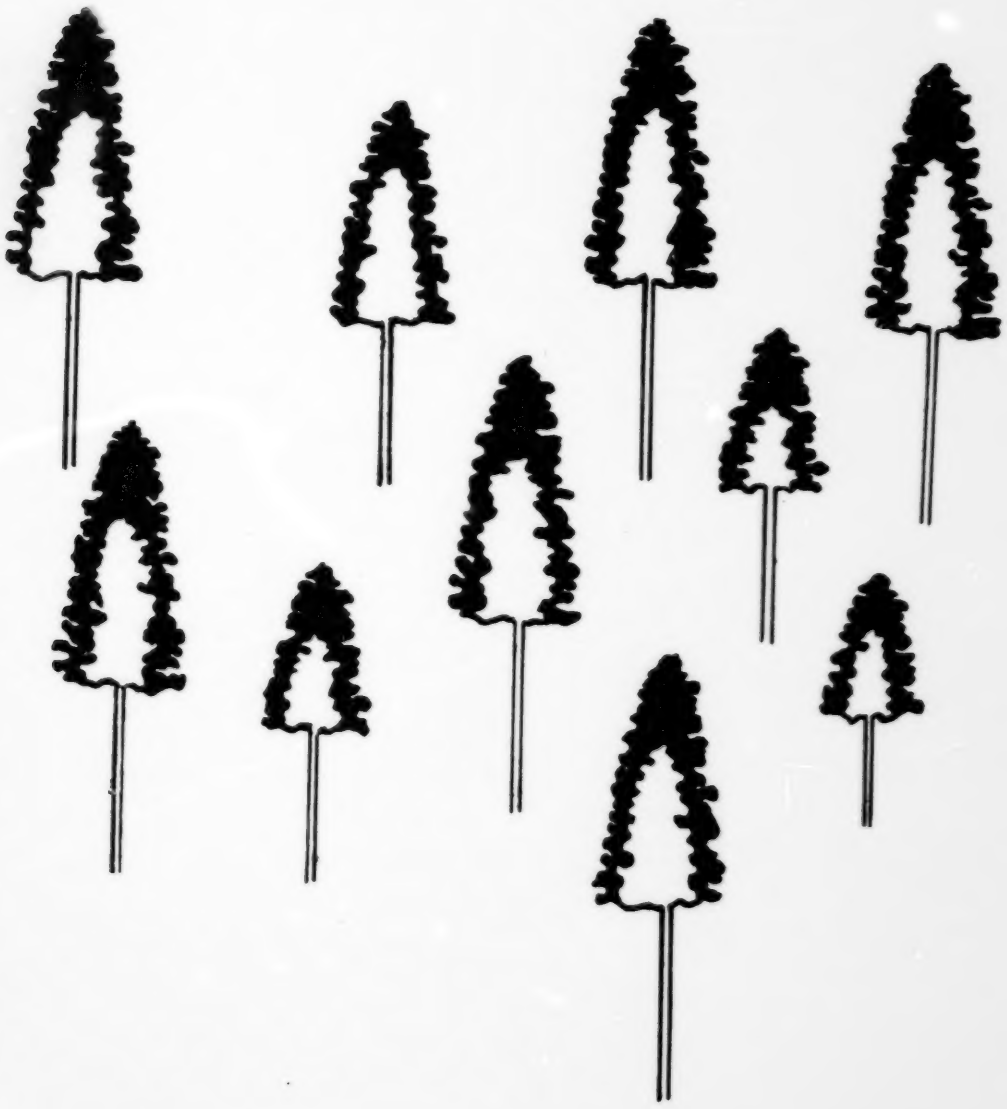
Initial Response of Partially Defoliated Black Spruce Trees to Precommercial Thinning

by P.F. Newton

Information Report N-X-264
1988

Canadian Forestry Service
Newfoundland Forestry Centre





89-00845/

NEWFOUNDLAND FORESTRY CENTRE

The Newfoundland Forestry Centre (NeFC) is an establishment of the Canadian Forestry Service. The Centre conducts most of the forestry research in the Newfoundland Region and is one of six similar regional establishments in Canada.

The objective of NeFC is to provide the scientific, technological and economic information and services required for the improvement, protection, and efficient utilization of the forest resources of the province of Newfoundland and Labrador. Its work is directed towards satisfying the requirements of the Provincial Government, the forest industry, federal agencies having forestry related programs and other clients of the Canadian Forestry Service; many of its studies are undertaken jointly with client agencies. The Centre attempts to bring the results of research to potential users by publishing information reports, articles in scientific journals, and by demonstrations of research results. It seeks to keep the public informed of its work by means of special displays, seminars, and related activities.

The NeFC program has three principal components - Forest Resources and Environmental Research, Forest Protection Research, and Forestry Development.

Initial Response of Partially Defoliated Black Spruce Trees to Precommercial Thinning

by P.F. Newton

INFORMATION REPORT N-X-264
1988
CANADIAN FORESTRY SERVICE
NEWFOUNDLAND FORESTRY CENTRE

© Minister of Supply and Services Canada 1988

ISBN No. 0-662-16309-5
Cat. No. Fo46-15/264E
ISSN No. 0704-7657

Copies of this report are available at no charge from:

Newfoundland Forestry Centre
Canadian Forestry Service
P.O. Box 6028
St. John's, Newfoundland
Canada A1C 5X8

Telephone No. 709-772-4117

OR

Microfiches of this publication may be purchased from:

Micro Media Inc.
Place du Portage
165, Hôtel-de-Ville
Hull, Quebec
J8X 3X2

Abstract

From 1975 to 1980 approximately 8000 ha of productive coniferous forests were precommercially thinned within insular Newfoundland. Coincidently a regional spruce budworm (*Choristoneura fumiferana* (Chem.)) outbreak peaked during this same period. This case study was initiated in order to evaluate the response of black spruce (*Picea mariana* (Mill.) B.S.P.) trees to precommercial thinning conducted during this period. The study areas consisted of two black spruce stands situated on medium sites within central insular Newfoundland. Both areas were partially thinned in 1977 at an age of 25 years. Results indicated that absolute and relative diameter, basal area and volume and specific volume increments were greater in the thinned than in the unthinned portions at each area within seven years of treatment. Live crown ratios were greater in the treated portions than in the untreated portions however there were no consistent differences in cylindrical form factor or specific gravity eight years after thinning. Only a limited number of these increases could be statistically attributed to thinning due partially to the inversely related effects of thinning and spruce budworm defoliation. These results suggest that unless protection programs are implemented during spruce budworm outbreaks only minimal gains will be realized from thinning black spruce stands.

Résumé

Une éclaircie précommerciale a été pratiquée de 1975 à 1980 sur près de 8 000 ha de forêt de conifères productive de l'île de Terre-Neuve. Le plus fort d'une épidémie régionale de la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* (Clem.)) a coïncidé avec cette période. Cette étude de cas a été entreprise pour évaluer la réaction d'épinettes noires (*Picea mariana* (Mill.) B.S.P.) à une éclaircie précommerciale effectuée pendant cette période. Les régions à l'étude abritaient deux peuplements d'épinettes noires occupant des stations moyennes du centre de l'île de Terre-Neuve. Une éclaircie partielle avait été pratiquée en 1977 dans les deux peuplements alors âgés de 25 ans. Les résultats de l'étude révèlent que l'accroissement absolu et relatif du diamètre, de la surface terrière et du cubage ainsi que du volume ligneux spécifique était plus élevé dans la partie éclaircie de chaque région à l'étude que dans la partie non éclaircie, sept ans après le traitement. Le rapport hauteur cime vivante/hauteur totale était plus élevé dans les parties éclaircies, sans toutefois que le coefficient de forme cylindrique ou le poids spécifique ne présentent de différences uniformes, huit ans après le traitement. Seule une certaine part de ces accroissements peut être statistiquement attribuée à l'éclaircie, partiellement en raison des effets connexes inverses de l'éciaircie et de la défoliation causée par la tordeuse des bourgeons de l'épinette. Ces résultats permettent de supposer que l'éclaircie de peuplements d'épinettes noires ne procurera que des avantages minimes si aucun programme de protection n'est mis en oeuvre lors d'épidémies de la tordeuse des bourgeons de l'épinette.

Table of Contents

	Page
ABSTRACT	iii
RÉSUMÉ	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
ACKNOWLEDGEMENTS	vii
INTRODUCTION	1
APPROACH	1
STUDY AREAS	1
Location	1
Site Description	1
Treatment	2
Defoliation History	2
METHOD	4
Data Acquisition	4
Computations	4
Statistical Analysis	4
RESULTS	6
DISCUSSION	21
Radial Growth	21
Specific Volume Increment	21
Live Crown Ratio	21
Specific Gravity	21
Initiation, Duration and Magnitude of Response	21
SUMMARY	22
LITERATURE CITED	22

List of Tables

Page

1a. Data description 5

1b. Percentage distribution of area classes by height class and associated number of sample trees (n) for each area 5

2. Annual and periodic diameter increment (DBHI) and relative diameter increment (RDBHI) at breast height differences relative to control trees by area and tree height-area class 8

3. Annual and periodic basal area increment (BAI) and relative basal area increment (RBAI) at breast height differences relative to control trees by area and tree height-area class 9

4. Annual and periodic total volume increment (TVI) and relative total volume increment (RTVI) differences relative to control trees by area and tree height-area class 10

5. Annual and periodic specific volume increment (SVI) differences relative to control trees by area and tree height-area class 11

6. Periodic live crown ratio, form factor and specific gravity response differences relative to control trees by area and tree height-area class 12

List of Figures

Page

1a. Number of degree days above 5 degrees celsius and precipitation data during the vegetative season by year within the study region 3

1b. Annual spruce budworm defoliation estimates for black spruce as determined from individual trees situated within eight impact plots located throughout the study region 3

2a. Annual and periodic absolute diameter increments at breast height for thinned (T) and control (C) trees by area and tree height-area class 13

2b. Annual and periodic relative diameter increments at breast height for thinned (T) and control (C) trees by area and tree height-area class 14

3a. Annual and periodic absolute basal area increments at breast height for thinned (T) and control (C) trees by area and tree height-area class 15

3b. Annual and periodic relative basal area increments at breast height for thinned (T) and control (C) trees by area and tree height-area class 16

4a. Annual and periodic absolute volume increments for thinned (T) and control (C) trees by area and tree height-area class 17

4b. Annual and periodic relative volume increments for thinned (T) and control (C) trees by area and tree height-area class 18

5. Annual and periodic specific volume increments for thinned (T) and control (C) trees by area and tree height-area class 19

6. Post-treatment, absolute and relative, periodic diameter, basal area and volume increments and specific volume increments for thinned (T) and control (C) trees by area and tree height-area class 20

Acknowledgements

The author expresses his appreciation to: Mr. B. Furey, Chief Forester, Abitibi-Price Inc., Grand Falls Division, for his cooperation during the course of this study; Mr. L. May, Technician, Newfoundland Forestry Centre (NeFC), Canadian Forestry Service (CFS) for his technical assistance; Dr. H. Piene, Research Scientist, Maritimes Forestry Centre, CFS, Dr. B. Titus and Dr. M. Lavigne, Research Scientists, NeFC, Mr. R. van Nostrand, Program Director, NeFC and Mr. B. Case, Program Director, Petawawa National Forestry Institute, CFS for their valuable comments and suggestions; and Dr. A. Raske, Research Scientist, NeFC for providing spruce budworm defoliation data.

Initial Response of Partially Defoliated Black Spruce Trees to Precommercial Thinning

by P.F. Newton

Introduction

The primary purpose of thinning is to concentrate the growth potential of an area onto a systematically selected number of stems by regulating the distribution of available growing space (Smith 1962). By this practice the quantity and quality of environmental factors responsible for growth are improved. For example, thinning increases temperature (Piene 1978), moisture supplies (Orr 1968), solar radiation, microbiological activity (Weetman et al. 1980) and rates of nutrient cycling (Piene 1978). As a result, improved economic yields through increased merchantable fibre production are attained.

In order to realize future fibre requirements forest managers within Newfoundland have undertaken an extensive silvicultural program employing precommercial thinning of young density-stressed coniferous stands as a principal forest improvement practice. During the period from 1975 to 1980 approximately 8000 hectares of productive forest land were precommercially thinned (Hayden 1986). Coincidently, however, a regional spruce budworm (*Choristoneura fumiferana* (Chem.)) outbreak peaked during this period and nearly all productive forests were moderately to severely defoliated for two or more years (Raske and Moody 1981). Quantitative response information from partially defoliated thinned areas is not currently available and thus forest managers are unable to evaluate their efforts.

In order to provide information concerning initial responses to operational precommercial thinning practices conducted during this outbreak a case study was initiated. Two partially thinned black spruce (*Picea mariana* (Mill.) B.S.P.) areas within central insular Newfoundland were evaluated. The parameters evaluated were diameter, basal area, volume and specific volume growth (Duff and Nolan 1957), cylindrical form factor (Husch et al. 1982), live crown ratio and specific gravity at breast height.

Approach

Evaluation of responses to operational precommercial thinning practices usually involves either nondestructive periodic measuring of permanent sample plots or the use of destructive stem analysis techniques within temporary sample plots. Nondestructive techniques describe annual responses implicitly whereas destructive stem analysis methods describe them explicitly. In areas, such as insular Newfoundland, where annual and periodic impacts are frequent due to insect defoliation (Otvos and Moody 1978; Otvos et al. 1979; Raske 1985), appreciation of extraneous impacts is critical for accurate response evaluation. In addition, by adjusting for response heterogeneity through stratification using tree size-area classes increases in sensitivity and precision can be achieved (Crown et al. 1977). Further, analysis of pretreatment growth characteristics by strata can determine the validity of subsequent post-treatment comparisons (Ballard and Majid 1985). Therefore the analysis employed involved the evaluation of both annual and periodic responses by height and tree area classes through destructive stem analysis techniques.

Study Areas

Location

The study areas were two geographically separated black spruce stands, denoted Area I (latitude 48-50′ N., longitude 55-59′ W.) and Area II (latitude 48-50′ N., longitude 55-58′ W.). Both areas are within Forest Section B28a-Grand Falls (Rowe 1972) and the North-central ecoregion (Damman 1983) of central insular Newfoundland on the Exploits River watershed.

Site Description

Within both areas the tree layer was dominated by black spruce (95%) with trembling aspen (*Populus tremuloides* Michx.) (5%) scattered throughout. Commonly occurring boreal shrubs, herbs, mosses and lichens were widely distributed, e.g., *Vaccium angustifolium* Ait., *Cornus canadensis* L., *Pleurozium schreberi* (BSG.) Mitt., *Cladina rangiferina* (L.) Web. The growing season is approximately 150 days beginning in mid-May and ending in early October (Damman 1976). Specifically, for the period from 1970 to 1984, inclusive, the annual average number of degree days above 5°C and precipitation data are graphically illustrated in Figure 1a. Climatic conditions during 1983 and 1984 were the most conducive

to vegetative growth whereas conditions in 1974 and 1978 were the least.

Ecologically the areas belong to the Black Spruce-Moss Forest Type situated on dry sandy loams and loamy sands (Damman 1964). However Area I was situated on a site slightly lower in quality than that of Area II, i.e., mean annual height increments of 0.21 and 0.23 m/yr for Areas I and II, respectively. Physical soil characteristics of each master horizon at each treatment and area were comparable.

Treatment

Within both areas approximately half of the original stand was precommercially thinned in 1977 and the remainder left unthinned. The objective of the thinning operation was to leave an acceptable density of crop trees as evenly spaced as possible throughout the treated area. Trees within both areas were approximately 25 years-old when they were thinned. Thinning reduced density from 13317 to 2295 stems/ha at Area I and from 16002 to 2425 stems/ha at Area II. Post-treatment spacings at Areas I and II were 2.1 m and 2.0 m, respectively.

Defoliation History

Historically, black spruce has been considered relatively resistant to severe spruce budworm damage (Blais 1957). However during a regional spruce budworm outbreak within central insular Newfoundland many black spruce trees incurred severe defoliation of current year foliage (Raske and Sutton 1986). Regional estimates of annual defoliation of black spruce trees, derived from eight impact plots (Bryant and Raske 1976; Raske and Rowe 1976; Raske (unpublished data)) located throughout the study region, were as follows: between 1971 and 1974 the degree of defoliation was 10% annually; from 1976 to 1980 annual defoliation peaked, averaging 74% per year; in 1981 spruce budworm populations collapsed (Raske 1985) and hence from 1981 to 1984 there was no evidence of defoliation (Figure 1b).

Within the specific study areas black spruce trees were similarly defoliated however, no quantitative estimates of the degree of defoliation were available. Previous terminal leader damage observed on approximately 100% of the trees within both areas provided evidence of past defoliation. There was no evidence of mortality due to the spruce budworm defoliation within either area. It was assumed therefore that the degree of defoliation was similar to that observed in the eight impact plots and approximately equivalent within treatments and between areas. Hence, slight growth losses during the period from 1971 to 1974 would be expected. From 1975 to 1982 significant growth losses would have occurred. For the remaining period, 1983 and 1984, growth rates would be returning to pre-defoliation levels. At the time of sampling, 1985, trees were exhibiting normal shoot growth and appeared to be fully recovered.

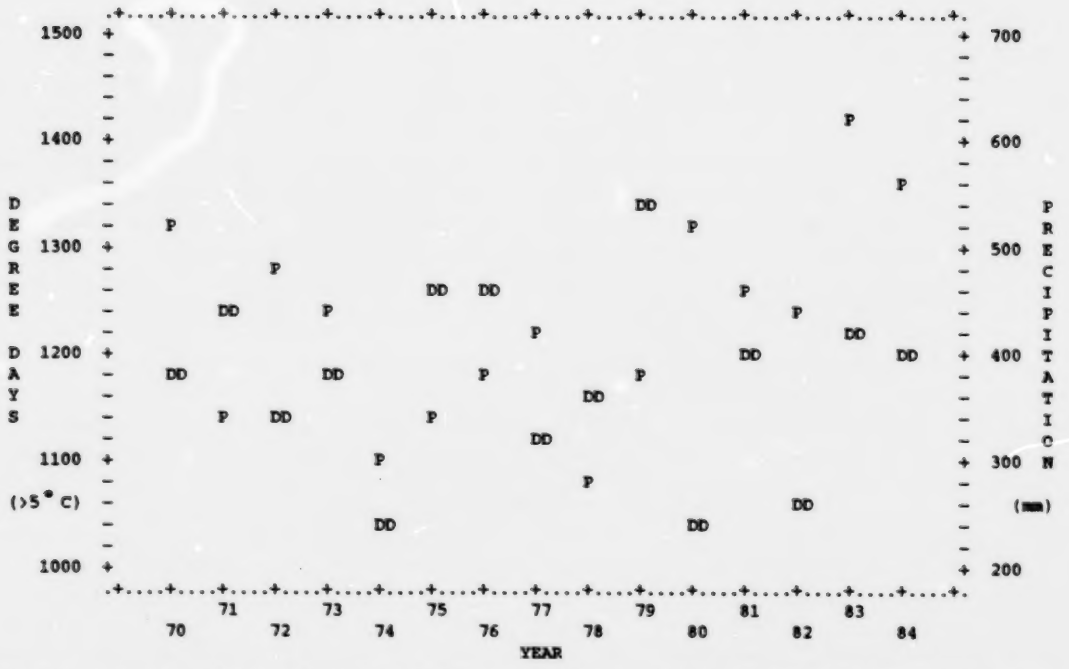


Figure 1a. Number of degree days above 5 degrees celsius and precipitation data during the vegetative season by year within the study region. Where P = precipitation in mm and DD = degree days. Data derived from the Atmospheric Environment Service's (Dept. of Environment, Canada) monthly reports for the Grand Falls and Exploits Dam weather stations from 1970 to 1984.

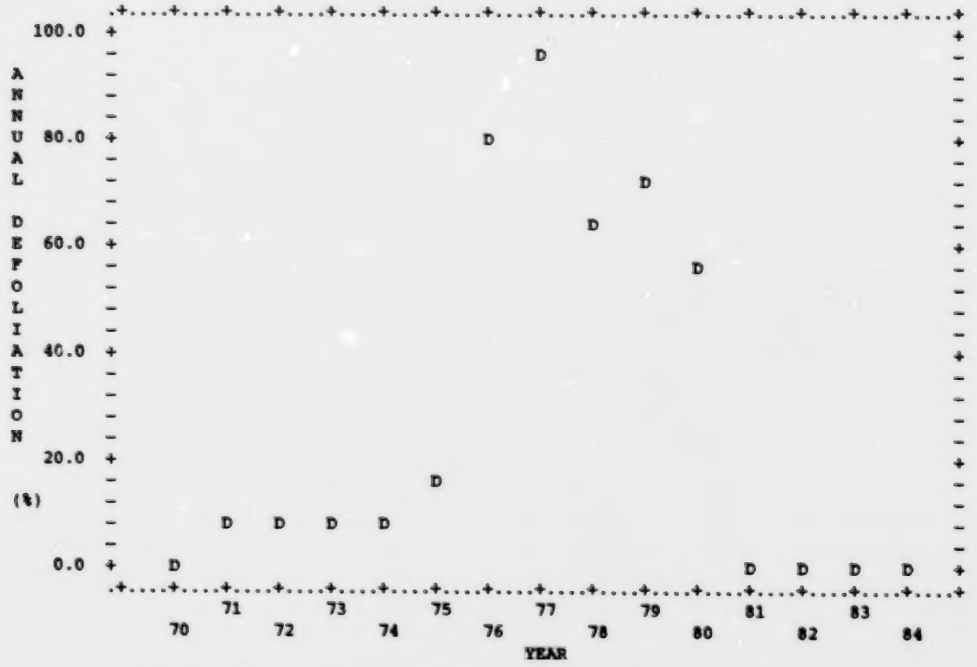


Figure 1b. Annual spruce budworm defoliation estimates for black spruce as determined from individual trees situated within eight impact plots located throughout the study region (i.e., Plots 34, 35, 50, 51, 52, 53, 54 and 55 (Bryant and Raske 1976; Raske and Rowe 1976)).

Method

Data Acquisition

Three 0.015 ha circular plots (7 m radius) were established in the unthinned and thinned portions of the stand at each area. Detailed location, treatment and site description information for each plot are tabulated in Table 1a. Data collected from each plot consisted of the following: (i) diameter at breast height (± 0.10 cm) and total height (± 0.01 m) measurements for all living and dead trees by species; (ii) age at stump height for all living and dead black spruce trees; (iii) polar coordinates for all living black spruce trees; (iv) diameters of residual black spruce stumps. Within each plot a 0.008 ha circular sub-plot (5 m radius) was established from which approximately two trees per diameter class (2 cm width) for the control plots and three trees per diameter class for the thinned plots were randomly selected for stem analysis. Specifically, 19 untreated and 27 treated trees were selected from Area I and 15 untreated and 23 treated trees were selected from Area II. Percent-height destructive stem analysis procedures were employed to obtain cross-sectional samples (i.e., sectioning the stem at 10% height intervals, and at stump and breast height). For each cross-section, annual ring widths from 1970 to 1984 were measured (± 0.001 cm) along three 120-degree sectors, sanded, cleaned and surface moisten radii using an Digi-Mic (Homan Electronic Controls Ltd.) ring counter.

Computations

Employing a Fortran-77 based algorithm the following annual and pre- and post-treatment (i.e. 1970-76 and 1978-84, respectively) estimates were computed: (i) absolute diameter (cm/interval), basal area (dm^2/interval) and volume increments (dm^3/interval); (ii) relative diameter, basal area and volume increments (percent/interval); (iii) specific volume increment (dm^3/dm^2/interval). In addition, annual inside bark diameters and corresponding heights were calculated.

Since percent-height sampling procedures were used height at a specific age was estimated by a second degree polynomial regression function. Parameters of the function were estimated using the height-age data obtained from cross-sections for each sample tree. The algorithm calculations were based on the following geometric assumptions: (i) the stump section was considered a cylinder; (ii) sections between the stump and tip were treated as a frustum of a cone; where increments were not continuous throughout sections, the sectional computations were based on a cone and the length of the section to a specific age was estimated from the height-age function; (iii) the tip was considered a cone.

The live crown ratio and cylindrical form factor were computed using 1985 measurements for each sample tree. Averaged from the three radii at breast height basic specific gravity for the post-treatment period was determined for each sample tree following the procedures given by TAPPI (1953).

Statistical Analysis

Sample trees were grouped into 1977 tree height-area classes by treatment and area (height at the beginning of the 1977 growing season). Two height classes, 4 m (3.1-5.0) and 6 m (5.1-7.0) were used. Trees in the 4 m and those in the 6 m height class were considered codominants and dominants. Trees within the thinned portions of each area were stratified into tree-area classes: 2.75 m^2 (1.75-3.74), 4.75 m^2 (3.75-5.74) and 6.75 m^2 (5.75-7.74). These area classes correspond to 3636, 2105 and 1481 stems/ha, respectively. Tree areas were calculated as follows: tree area (m^2) = (3.14/4)•(mean inter-tree distance (m) squared), where the mean inter-tree distance is the average distance from the sample tree to the nearest neighbor in each quadrant. Trees within the control portions of each area were stratified into one tree area class, 0.87 m^2 (< 1.75). This area class is equivalent to 11494 stems/ha. Due to the relatively small number of codominant trees within the thinned portions of each area only one tree area class 4.75 m^2 was sampled. All three area classes within the 6 m height class were sampled. The proportional distribution of the tree height-area classes within the two areas and associated number of sample trees are listed in Table 1b.

The significance of treatment differences by tree height-area class, parameter and year or period was determined by a Student t-test. Homogeneity of treatment variances by area, tree height-area class, growth parameter and year or period were tested using a F-test at the 5% significance level. For non-significant variance differences a pooled Student t-test was used, i.e., pooling the two estimates of the variance. For significant variance differences a separate Student t-test was employed, i.e., the variance of each treatment was estimated separately. All Student t-tests were conducted at the 5% significance level at a power of 0.80.

Table 1a: Data description.

AREA	PLOT NO.	TR[a]	LOCATION LONGITUDE (° ′ ″)	LOCATION LATITUDE (° ′ ″)	ELEV (m)	SLOPE (%)	ASPECT (°)	AGE (yrs)	DHT[b] (m)	SITE QUALITY (m/yr)	DENSITY 1976	TREATMENT[c] (stems/ha) 1985	SPACING (m)	SPATIAL DISTRIBUTION 1985 $\bar{x}/\bar{d}$	SPATIAL DISTRIBUTION 1985 PATTERN
I	1	C	55 59 26	48 57 54	130	2	147	32	6.7	0.21	16306	15656	—	1.075	random
	2	C	55 59 18	48 57 47	130	0	—	31	6.8	0.22	11953	11498	—	1.480	random
	3	C	55 59 09	48 57 46	130	2	129	31	6.7	0.22	15786	15786	—	1.580	random
	4	T	55 59 20	48 57 44	130	2	198	34	6.8	0.20	17474	3053	1.81	1.143	random
	5	T	55 59 13	48 57 41	130	4	216	36	7.2	0.20	14032	2014	2.23	0.605	random
	6	T	55 59 07	48 57 34	130	0	—	33	7.1	0.22	8445	1819	2.34	1.318	random
II	7	C	55 58 34	48 57 02	114	7	26	35	8.1	0.23	4417	4417	—	0.837	random
	8	C	55 58 44	48 57 10	114	2	298	33	7.3	0.22	20462	19293	—	0.623	random
	9	C	55 58 33	48 57 11	114	4	226	32	7.2	0.23	15415	14941	—	1.033	random
	10	T	55 58 00	48 57 10	114	5	127	34	7.7	0.23	17735	2209	2.13	1.086	random
	11	T	55 58 13	48 57 11	114	12	194	36	8.1	0.23	22607	2144	2.16	0.862	random
	12	T	55 58 05	48 57 17	114	6	158	33	7.2	0.22	7665	2923	1.85	0.779	random

AREA	PLOT NO	TR	FOREST VEGETATION (% by basal area)			SPECIES COMPOSITION[e]				LESSER VEGETATION (% cover)				SOILS[f] FH pH	A pH	A %MC	A %OM	B pH	B %MC	B %OM	B HOZ	B TXT	GREAT GROUP	DAMMAN FOREST TYPE[g]
I	1	C	PIm-95	BEpa-4	POt-1	COc-1	DIu-37	PLs-30						4.1	3.9	4	15	4.9	1	6	Bfh	SL	FH	III-1
	2	C	PIm-91	POt-8	BEpa-1	VAa-1	COc-1	DIu-13	PLs-87					4.6	3.8	2	8	4.7	6	18	Bhf	SL	HF	III-1
	3	C	PIm-100			DIu-10	PLs-83	CLr-7						3.9	3.9	3	15	4.6	6	20	Bhf	SCL	HF	III-1
	4	T	PIm-98	POt-2		VAa-1	COc-1	DIu-13	PLs-75					3.9	4.0	1	3	4.9	6	14	Bhf	SL	HF	III-1
						HPc-10	CLr-1																	
	5	T	PIm-95	POt-5		VAa-1	COc-1	DIu-20	PLs-79					4.3	4.1	3	15	4.9	3	9	Bfh	SL	FH	III-1
	6	T	PIm-100			VAa-1	COc-1	PLs-81	CLr-18					3.9	4.1	3	12	4.6	4	15	Bhf	SL	HF	III-1
II	7	C	PIm-88	POt-10	LAl-2	KAa-4	DIu-2	PLs-96	HPc-2					4.2	3.8	3	13	5.2	4	9	Bfh	SL	FH	III-1
	8	C	PIm-93	POt-7		DIu-17	PLs-83							3.7	3.7	2	9	4.7	4	15	Bhf	SL	HF	III-1
	9	C	PIm-85	POt-14	ABb-1	COc-1	DIu-7	PLs-92						3.9	3.7	3	17	5.5	2	6	Bfh	SL	FH	III-1
	10	T	PIm-99	POt-1		VAa-2	COc-7	DIu-30	PLs-49					4.0	4.1	4	20	4.7	7	22	Bhf	L	HF	III-1
						HPc-12	CLr-2																	
	11	T	PIm-95	POt-5		COc-1	DIu-7	PLs-90	CLr-3					3.7	3.7	3	13	5.0	3	11	Bhf	SL	HF	III-1
	12	T	PIm-96	POt-4		VAa-3	COc-1	DIu-27	PLs-62					3.9	3.6	3	12	5.3	3	8	Bfh	LS	FH	III-1
						CLr-10																		

a; TR = Treatment; C = control or unthinned plots and T = treatment or thinned plots.

b; Mean dominant height.

c; 1976 values determined through residual stumps.

d; Pielou (1959) non-randomness index.

e; Forest vegetation species codes: PIm-Picea mariana (Mill.) B.S.P., POt-Populus tremuloides Michx., BEpa-Betula papyrifera Marsh., ABb-Abies balsamea (L.) Mill., LAl-Larix laricina (Du Roi) K. Koch. Lesser vegetation by plant class, i.e., Shrubs: VAa-Vaccium angustifolium Ait., KAa-Kalmia angustifolia L. Herbs: COc-Cornus canadensis L., DIu-Dicranum undulatum Bird. Mosses: PLs-Pleurozium schreberi (BSG.) Mitt., HPc-Hypnum crista-castresis Hedw. Lichens; CLr-Cladina rangiferina (L.) Web.

f; pH determined potentiometrically; %MC = percent moisture content; %OM = percent organic matter content determined by loss-on-ignition method; HOR = horizon; TXT = particle-size distribution determined hydrometrically (Black 1965) and classified according to a texture triangle where L = loam, LS = loamy sand, SL = sandy loam and SCL = sandy clay loam; Great groups FH-ferro-humic and HF-humo-ferric (Canadian Soil Survey Committee 1978).

g; III-1 = Black spruce-moss forest type on dry sandy loams and loamy sands (Damman 1964).

Table 1b: Percentage distribution of area classes by height class and associated number of sample trees (n) for each area.

HEIGHT CLASS (m)	CONTROL (<1.75 m²) AREA I %	AREA I n	CONTROL (<1.75 m²) AREA II %	AREA II n	THINNED TREE AREA CLASS (m²) 2.75 AREA I %	2.75 AREA I n	2.75 AREA II %	2.75 AREA II n	4.75 AREA I %	4.75 AREA I n	4.75 AREA II %	4.75 AREA II n	6.75 AREA I %	6.75 AREA I n	6.75 AREA II %	6.75 AREA II n
4	97	9	95	7	—	—	—	—	33	5	32	4	—	—	—	—
6	96	10	86	8	41	9	51	11	23	9	16	5	6	4	10	3

Results

Absolute and relative diameter, basal area and volume increment differences by area and tree height-area class are listed in Tables 2, 3 and 4, and graphically illustrated in Figures 2a,b, 3a,b and 4a,b, respectively. Specific volume increment differences by area and tree height-area class are presented in Table 5 and shown on Figure 5. Post-treatment periodic absolute and relative diameter, basal area and volume increments, and specific volume increments are illustrated in Figure 6. Live crown ratio, cylindrical form factor and basic specific gravity treatment differences by area and tree height-area class are tabulated in Table 6.

The following discussion is restricted to the significant (5% level) effects of thinning. The responses by tree height-area class and area were as follows.

(i) Tree height-area class: 4 m-4.75 m^2.

Area I: Significant pre-treatment periodic differences in terms of absolute and relative diameter, relative basal area, and specific volume increments, negated subsequent response evaluation (Tables 2, 3 and 5; Figures 2a,b, 3b and 5). Pre-treatment increment variation within codominant trees may be due to the changing status of these trees in regards to their competitive position during this period.

Area II: On an annual basis, increases in absolute diameter increments of 0.13 to 0.17 cm were evident during the period from 1980 to 1984 (Table 2; Figure 2a). Further, increases in relative diameter of 1.0 to 2.9% and basal area of 2.1 to 6.0% were apparent throughout the period from 1979 to 1984 (Tables 2 and 3; Figures 2b and 3b). During 1981 an increase in absolute volume increment of 0.450 dm^3 occurred and from 1979 to 1982, and in 1984 relative volume increments increased by 2.5 to 5.3% (Table 4; Figures 4a,b). Specific increments increased by 0.010 to 0.014 dm^3/dm^2 during the period from 1980 to 1982 and in 1984 (Table 5; Figure 5). On a periodic basis, increases of 0.81 cm and 16.6% in absolute and relative diameter increments were detected during the post-treatment period (Table 2; Figures 2a,b and 6). In addition, gains of 40.6% and 38.4% in relative basal area and volume increments, and 0.099 dm^3/dm^2 in specific volume increment were evident for the same period (Tables 3, 4 and 5; Figures 3b, 4b, 5 and 6).

(ii) Tree height-area class: 6 m-2.75 m^2.

Area I: Annually, only an increase in specific volume increment of 0.007 dm^3/dm^2 in 1980 was significant (Table 5; Figure 5).

Area II: On an annual basis increases in absolute diameter of 0.08 to 0.14 cm were detected in 1981, 1982 and 1984 (Table 2; Figure 2a). In addition, gains in absolute basal area increment of 0.024 dm^2 in 1982 and specific volume increment of 0.009 dm^3/dm^2 in 1981 were evident (Tables 3 and 5; Figures 3a and 5). Due to significant periodic differences in relative diameter, basal area and volume increments during the pre-treatment period analysis of post-treatment relative responses was not attempted (Tables 2, 3 and 4; Figures 2b, 3b and 4b).

(iii) Tree height-area class: 6 m-4.75 m^2.

Area I: An annual increase in absolute diameter increment of 0.10 cm in 1980 was significant (Table 2; Figure 2a). Increases in absolute basal area increments of 0.010 to 0.020 dm^2 were evident from 1979 to 1982 (Table 3; Figure 3a). Improvements in absolute volume increments of 0.637 to 0.776 dm^3 were detected in 1979, 1980 and 1982 (Table 4; Figure 4a). Further, an increase in specific volume increment of 0.010 dm^3/dm^2 were apparent in 1979 and 1980 (Table 5; Figure 5). Periodically, increases of 0.67 cm in absolute diameter and 0.121 dm^2 in basal area increments during the post-treatment period were evident (Tables 2 and 3; Figures 2a, 3a and 6). Live crown ratios increased by 16.20% eight years after treatment (Table 6).

Area II: There were no significant thinning effects on absolute or relative diameter, basal area, volume or specific volume increments (Tables 2, 3, 4 and 5; Figures 2a,b, 3a,b, 4a,b, 5 and 6). In addition, no thinning effects were detected in terms of live crown ratio, cylindrical form factor or basic specific gravity (Table 6).

(iv) Tree height-area class: 6 m-6.75 m^2.

Area I: On an annual basis, increases of 0.14 cm in absolute diameter, 0.021 dm^2 in basal area and 0.951 dm^3 in volume increments occurred in 1980 (Tables 2, 3 and 4; Figures 2a, 3a and 4a). In addition an increase of 2.7% in relative volume and 0.013 dm^3/dm^2 in specific volume increment in 1980 were significant (Tables 4 and 5; Figures 4b and 5). Periodically, absolute diameter increment increased by 0.99 cm and relative diameter increased by 10.6% during the post-treatment period (Table 2; Figures 2a,b and 6). In addition relative basal area increment increased by 25.1% and specific volume increment by 0.125 dm^3/dm^2 (Tables 3 and 5; Figures 3b, 5 and 6). Further, there was a significant increase of 14.39% in live crown ratio (Table 6).

Area II: Annual increases in absolute diameter increment of 0.16 to 0.20 cm were apparent during the

period from 1979 to 1982 (Table 2; Figure 2a). Similarly, increases in relative diameter increment of 1.9 to 2.2% and relative basal area increment of 4.0 to 4.4% were evident for the same period (Tables 2 and 3; Figures 2b and 3b). Increases of 4.9% in relative volume increment and 0.016 dm^3/dm^2 in specific volume increments occurred in 1979 (Table 4 and 5; Figures 4b and 5). A periodic gain in absolute diameter increment of 1.04 cm was apparent during the post-treatment period (Table 2; Figures 2a and 6).

Table 2: Annual and periodic diameter increment (DBHI) and relative diameter increment (RDBHI) at breast height differences relative to control trees by area and tree height-area class.

AREA I

YEAR	HEIGHT CLASS (m)															
	4.0				6.0											
	TREE AREA CLASS (m²)															
	4.75				2.75				4.75				6.75			
	(nc = 9)[a]			(nt = 5)[a]	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 4)
	F[b]	DBHI[c] (cm)	F	RDBHI[c] (%)	F	DBHI (cm)	F	RDBHI (%)	F	DBHI (cm)	F	RDBHI (%)	F	DBHI (cm)	F	RDBHI (%)
1970	*	+.1563*	*	+5.11	ns	−.0311	ns	+0.46	ns	+.0675	ns	+0.40	ns	+.1134	ns	+2.22
1971	ns	+.0798	ns	+1.71	ns	−.0055	ns	−0.57	ns	+.0657	ns	+0.08	ns	+.0721	ns	+0.84
1972	ns	+.1336*	ns	+2.77*	ns	−.0124	ns	−0.47	ns	+.0317	ns	+0.42	ns	+.0889	ns	+1.17
1973	ns	+.1269*	ns	+2.33*	ns	−.0302	ns	−0.59	ns	+.0027	ns	+0.56	ns	+.0591	ns	+0.65
1974	ns	+.1057	ns	+1.54	*	−.0082	*	−0.24	ns	+.0419	ns	+0.04	ns	+.0773	ns	+0.74
1975	ns	+.1154*	ns	+1.59	ns	+.0008	ns	+0.01	ns	+.0368	ns	+0.06	ns	+.0391	ns	+0.27
1976	ns	+.1034*	ns	+1.41*	ns	−.0187	ns	−0.25	ns	+.0347	ns	+0.12	ns	+.0403	ns	+0.31
PRE[d]	ns	+.8211*	ns	+25.74*	ns	−.0433	ns	−2.67	ns	+.2809	ns	−0.71	ns	+.4901	ns	+8.73
1978	ns	+.0727	ns	+0.64	*	+.0140	*	+0.15	ns	+.0954	*	+0.98	ns	+.0467	ns	+0.32
1979	ns	+.1014	ns	+1.24	ns	+.0470	ns	+0.64	ns	+.1281	*	+1.36	ns	+.1129	ns	+1.25
1980	ns	+.1000*	ns	+1.29*	ns	+.0520	ns	+0.65	ns	+.0958*	ns	+0.89	ns	+.1388*	ns	+1.48
1981	ns	+.0470	ns	+0.50	ns	+.0338	ns	+0.39	ns	+.0500	ns	+0.33	ns	+.0624	ns	+0.51
1982	ns	+.0498	ns	+0.55	ns	+.0409	ns	+0.47	ns	+.0691	ns	+0.56	ns	+.1115	ns	+1.04
1983	ns	+.0882	ns	+0.96	ns	+.0488	ns	+0.51	ns	+.0969	ns	+0.66	ns	+.2385	ns	+2.17
1984	ns	+.1152	ns	+1.01	ns	+.1318	ns	+1.42	ns	+.1303	ns	+0.81	ns	+.2787	ns	+2.47
POST[d]	ns	+.5743	ns	+7.23	ns	+.3682	ns	+4.79	ns	+.6657*	ns	+6.37	ns	+.9895*	ns	+10.60*

AREA II

YEAR	HEIGHT CLASS (m)															
	4.0				6.0											
	TREE AREA CLASS (m²)															
	4.75				2.75				4.75				6.75			
	(nc = 7)			(nt = 4)	(nc = 8)			(nt = 11)	(nc = 8)			(nt = 5)	(nc = 8)			(nt = 3)
	F	DBHI (cm)	F	RDBHI (%)	F	DBHI (cm)	F	RDBHI (%)	F	DBHI (cm)	F	RDBHI (%)	F	DBHI (cm)	F	RDBHI (%)
1970	*	+.0086	*	+1.21	ns	−.0217	ns	−2.12	ns	−.0845	ns	−2.26	ns	−.0434	ns	−1.33
1971	*	+.0060	ns	+0.61	ns	−.0539	ns	−2.27	ns	−.0669	ns	−1.59	ns	−.0332	ns	−0.43
1972	*	+.0455	*	+1.31	ns	−.0245	ns	−1.27	ns	−.0267	ns	−0.60	ns	+.0102	ns	+0.36
1973	*	+.0047	ns	0.00	ns	−.0468	ns	−1.44*	ns	−.0740	ns	−1.20	ns	−.0432	ns	−0.52
1974	*	−.0041	ns	−0.11	ns	−.0377	ns	−1.08	ns	−.0417	ns	−0.60	ns	−.0142	ns	−0.11
1975	ns	−.0253	ns	−0.57	ns	−.0429	ns	−0.98*	ns	−.0319	ns	−0.44	ns	−.0177	ns	−0.17
1976	ns	−.0028	ns	+0.16	ns	−.0655	ns	−1.32*	ns	−.0593	ns	−0.84	ns	−.0376	ns	−0.47
PRE	*	+.0326	*	+5.56	ns	−.2929	ns	−14.48*	ns	−.3850	ns	−10.29	ns	−.1791	ns	−3.63
1978	ns	+.0065	ns	+0.23	ns	+.0110	*	−0.32	ns	−.0397	ns	−0.48	ns	+.0374	ns	+0.66
1979	*	+.0529	ns	+1.04*	ns	+.0355	*	+0.29	ns	+.0211	*	+0.32	ns	+.1630*	ns	+2.16*
1980	ns	+.1264*	ns	+2.39*	ns	+.0444	ns	+0.33	ns	+.0224	ns	+0.27	ns	+.1636*	ns	+1.92*
1981	*	+.1502*	ns	+2.66*	*	+.1144*	*	+1.09*	*	+.0563	*	+0.62	ns	+.1963*	ns	+2.12*
1982	ns	+.1704*	ns	+2.92	*	+.1440*	ns	+1.32*	*	+.0510	ns	+0.51	ns	+.2005*	ns	+2.01*
1983	ns	+.1607*	ns	+2.60*	ns	+.1117	ns	+0.77	ns	+.0232	ns	+1.50	ns	+.1593	ns	+1.34
1984	ns	+.1402*	ns	+2.12*	*	+.0781*	ns	+0.39	ns	+.0134	ns	+1.20	ns	+.1159	ns	+0.87
POST	*	+.8074*	ns	+16.58*	ns	+.5171	*	+4.69	ns	+.1478	ns	+1.85	ns	+1.0360*	*	+13.53

a; nc,nt = number of control and treated trees used in calculating mean values, respectively.
b; F-test of homogeneity of variance of control and treated trees.
c; Significance of differences determined by appropriate t-test, as determined in b.
d; PRE,POST = pre- and post-treatment periods, i.e., 1970-76 and 1978-84, respectively.
* Significant at the 5% level of significance.

Table 3: Annual and periodic basal area increment (BAI) and relative basal area increment (RBAI) at breast height differences relative to control trees by area and tree height-area class.

AREA I

YEAR	HEIGHT CLASS (m) 4.0 — TREE AREA CLASS (m²) 4.75				HEIGHT CLASS (m) 6.0 — TREE AREA CLASS (m²) 2.75				4.75				6.75			
	(nc = 9)[a]			(nt = 5)[a]	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 4)
	F[b]	BAI[c] (dm²)	F	RBAI[c] (%)	F	BAI (dm²)	F	RBAI (%)	F	BAI (dm²)	F	RBAI (%)	F	BAI (dm²)	F	RBAI (%)
1970	ns	+.0088*	*	+11.62	ns	+.0034	ns	+0.99	ns	+.0107	ns	+0.85	ns	+.0101	ns	+4.82
1971	ns	+.0063	ns	+3.78	ns	+.0014	ns	−1.25	ns	+.0124	ns	+0.16	ns	+.0088	ns	+1.81
1972	ns	+.0110	ns	+6.05*	ns	+.0002	ns	−1.03	ns	+.0094	ns	−0.94	ns	+.0108	ns	+2.49
1973	ns	+.0113*	ns	+4.98*	ns	−.0025	ns	−1.25	ns	+.0048	ns	−1.18	ns	+.0080	ns	+1.38
1974	ns	+.0112	ns	+3.30	ns	−.0002	*	−0.52	ns	+.0096	ns	+0.08	ns	+.0115	ns	+1.55
1975	ns	+.0127	ns	+3.34	ns	+.0002	ns	+0.02	ns	+.0084	ns	+0.12	ns	+.0068	ns	+0.57
1976	ns	+.0116*	ns	+2.93*	ns	−.0022	ns	−0.54	ns	+.0076	ns	+0.24	ns	+.0070	ns	+0.64
PRE[d]	ns	+.0730	*	+88.44*	ns	.0000	ns	−9.28	ns	+.0628	ns	−3.28	ns	+.0628	ns	+26.26
1978	ns	+.0105	ns	+1.34	ns	+.0021	*	+0.28	ns	+.0153	*	+2.06	ns	+.0088	ns	+0.64
1979	ns	+.0129	ns	+2.56	ns	+.0058	ns	+1.31	ns	+.0195*	*	+2.83	ns	+.0165	ns	+2.59
1980	ns	+.0123	ns	+2.63*	ns	+.0068	ns	+1.33	ns	+.0161*	ns	+1.82	ns	+.0209*	ns	+3.05
1981	ns	+.0065	ns	+1.01	ns	+.0047	ns	+0.79	ns	+.0099*	ns	+0.67	ns	+.0110	ns	+1.04
1982	ns	+.0068	ns	+1.10	ns	+.0057	ns	+0.95	*	+.0126*	ns	+1.13	*	+.0187	ns	+2.11
1983	ns	+.0124	ns	+1.96	ns	+.0073	ns	+1.05	ns	+.0194	ns	+1.35	*	+.0417	ns	+4.47
1984	*	+.0184	ns	+2.10	ns	+.0200	ns	+2.96	ns	+.0278	ns	+1.68	*	+.0505	ns	+5.13
POST[d]	ns	+.0798	ns	+17.41	ns	+.0523	ns	+11.20	ns	+.1206*	ns	+15.08	*	+.1680	ns	+25.10*

AREA II

YEAR	HEIGHT CLASS (m) 4.0 — TREE AREA CLASS (m²) 4.75				HEIGHT CLASS (m) 6.0 — TREE AREA CLASS (m²) 2.75				4.75				6.75			
	(nc = 7)			(nt = 4)	(nc = 8)			(nt = 11)	(nc = 8)			(nt = 5)	(nc = 8)			(nt = 3)
	F	BAI (dm²)	F	RBAI (%)	F	BAI (dm²)	F	RBAI (%)	F	BAI (dm²)	F	RBAI (%)	F	BAI (dm²)	F	RBAI (%)
1970	ns	−.0012	*	+2.88	ns	+.0037	ns	−4.90	ns	−.0066	ns	−4.89	ns	−.0016	ns	−2.93
1971	*	−.0006	ns	+1.54	ns	−.0002	ns	−4.89	ns	−.0061	ns	−3.42	ns	−.0036	ns	−0.90
1972	*	+.0028	*	+2.90	ns	+.0012	ns	−2.67	ns	−.0031	ns	−1.25	ns	+.0002	ns	−0.79
1973	*	+.0010	ns	−0.09	ns	−.0018	ns	−3.06*	ns	−.0091	ns	−2.53	ns	−.0056	ns	−1.11
1974	*	+.0002	ns	−0.21	ns	−.0016	ns	−2.27*	ns	−.0059	ns	−1.27	ns	−.0023	ns	−0.24
1975	*	−.0015	ns	−1.19	ns	−.0031	ns	−2.02*	ns	−.0048	ns	−0.90	ns	−.0028	ns	−0.34
1976	ns	−.0004	ns	+0.33	ns	−.0056	ns	−2.74	ns	−.0081	ns	−1.75	ns	−.0051	ns	−0.98
PRE	*	+.0002	*	+25.98	ns	−.0072	ns	−42.63*	ns	−.0436	ns	−30.14	ns	−.0207	ns	−10.64
1978	ns	+.0006	ns	+0.48	ns	−.0005	*	−0.64	ns	−.0062	ns	−0.97	ns	+.0030	ns	+1.37
1979	*	+.0049	ns	+2.13*	ns	+.0055	*	+0.59	ns	+.0016	ns	+0.65	ns	+.0205	ns	+4.44*
1980	*	+.0116	ns	+4.93*	ns	+.0075	ns	+0.68	ns	+.0024	ns	+0.55	*	+.0232	ns	+3.96*
1981	*	+.0146	ns	+5.45*	ns	+.0180	*	+2.25*	ns	+.0076	*	+1.28	*	+.0300	ns	+4.37*
1982	*	+.0171	ns	+6.01*	ns	+.0236*	ns	+2.73*	ns	+.0074	ns	+1.06	*	+.0329	ns	+4.16*
1983	ns	+.0175	ns	+5.39*	ns	+.0212	ns	+1.61	ns	+.0039	ns	+0.31	*	+.0298	ns	+2.80
1984	*	+.0160	ns	+4.36*	ns	+.0170	ns	+0.81	ns	+.0019	ns	+0.24	*	+.0235	ns	+1.79
POST	*	+.0825	ns	+40.64*	ns	+.0919	*	+11.76	ns	+.0185	ns	+4.69	*	+.1629	*	+34.30

a; nc,nt = number of control and treated trees used in calculating mean values, respectively.
b; F-test of homogeneity of variance of control and treated trees.
c; Significance of differences determined by appropriate t-test, as determined in b.
d; PRE,POST = pre- and post-treatment periods, i.e., 1970-76 and 1978-84, respectively.
* Significant at the 5% level of significance.

Table 4: Annual and periodic total volume increment (TVI) and relative total volume increment (RTVI) differences relative to control trees by area and tree height-area class.

AREA I

YEAR	HEIGHT CLASS (m) 4.0 — TREE AREA CLASS (m²) 4.75				HEIGHT CLASS (m) 6.0 — TREE AREA CLASS (m²) 2.75				4.75				6.75			
	(nc = 9)[a]			(nt = 5)[a]	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 4)
	F[b]	TVI[c] (dm³)	F	RTVI[c] (%)	F	TVI (dm³)	F	RTVI (%)	F	TVI (dm³)	F	RTVI (%)	F	TVI (dm³)	F	RTVI (%)
1970	ns	+ .2008	ns	+ 6.06*	ns	+ .1146	ns	+ 0.91	ns	+ .4015	ns	+ 0.41	ns	+ .4893	ns	+ 3.58
1971	ns	+ .0992	ns	+ 0.53	ns	+ .0339	*	− 1.52	ns	+ .4699	ns	− 0.69	ns	+ .4408	ns	+ 0.64
1972	ns	+ .2846	ns	+ 3.99	ns	− .0055	ns	− 0.94	ns	+ .4084	ns	− 1.12	ns	+ .4394	ns	+ 0.77
1973	ns	+ .3179	ns	+ 3.70*	ns	− .0505	ns	− 0.86	ns	+ .3766	ns	− 0.60	ns	+ .4241	ns	+ 0.82
1974	ns	+ .2984	ns	+ 1.83	ns	− .0179	ns	− 0.68	ns	+ .4946	ns	− 0.03	ns	+ .4468	ns	+ 0.05
1975	ns	+ .4142	ns	+ 2.88	ns	+ .0807	ns	+ 0.46	ns	+ .4819	ns	+ 0.29	ns	+ .3160	ns	+ 0.29
1976	ns	+ .3993	ns	+ 2.82*	ns	− .0018	ns	− 0.18	ns	+ .3800	ns	+ 0.17	ns	+ .3270	ns	+ 0.22
PRE[d]	ns	+ 2.0146	ns	+ 38.94	ns	+ .1535	ns	− 9.11	ns	+ 3.0128	ns	− 6.57	ns	+ 2.8835	ns	+ 4.77
1978	ns	+ .3342	ns	+ 1.03	ns	+ .1751	ns	+ 0.74	ns	+ .5549	ns	+ 0.95	ns	+ .4931	ns	+ 0.86
1979	ns	+ .4578	ns	+ 2.76	ns	+ .3439	ns	+ 1.73	ns	+ .7283*	ns	+ 2.03	ns	+ .7911	ns	+ 2.32
1980	ns	+ .3897	*	+ 2.10*	ns	+ .4205	ns	+ 1.86	ns	+ .7755*	ns	+ 2.00	ns	+ .9513*	ns	+ 2.67*
1981	ns	+ .1292	ns	+ 0.02	ns	+ .1990	ns	+ 0.63	ns	+ .4801	ns	+ 0.61	ns	+ .5339	ns	+ 0.78
1982	ns	+ .1796	ns	+ 0.42	ns	+ .3472	ns	+ 1.32	*	+ .6366*	ns	+ 1.17	*	+ 1.0174	ns	+ 2.37
1983	ns	+ .3264	ns	+ 0.82	ns	+ .3617	ns	+ 1.14	ns	+ .9141	ns	+ 1.17	*	+ 2.1495	ns	+ 4.88
1984	ns	+ .5078	ns	+ 0.66	ns	+ .8937	ns	+ 2.82	ns	+ 1.2761	ns	+ 1.25	ns	+ 2.6327	ns	+ 5.12
POST[d]	ns	+ 2.3248	ns	+ 9.83	ns	+ 2.7411	ns	+ 12.69	ns	+ 5.3655	ns	+ 11.44	*	+ 8.5689	ns	+ 24.52

AREA II

YEAR	HEIGHT CLASS (m) 4.0 — TREE AREA CLASS (m²) 4.75				HEIGHT CLASS (m) 6.0 — TREE AREA CLASS (m²) 2.75				4.75				6.75			
	(nc = 7)			(nt = 4)	(nc = 8)			(nt = 11)	(nc = 8)			(nt = 5)	(nc = 8)			(nt = 3)
	F	TVI (dm³)	F	RTVI (%)	F	TVI (dm³)	F	RTVI (%)	F	TVI (dm³)	F	RTVI (%)	F	TVI (dm³)	F	RTVI (%)
1970	ns	− .0378	*	− 0.12	ns	+ .0465	ns	− 5.41*	ns	− .2036	ns	− 3.92	ns	− .0396	ns	− 2.65
1971	ns	− .0993	*	− 2.84	ns	− .0400	ns	− 5.46*	ns	− .1596	ns	− 2.12	ns	− .1131	ns	+ 0.83
1972	*	− .0615	ns	− 1.81	*	+ .0235	ns	− 2.76	ns	− .0624	ns	− 0.17	ns	+ .0486	ns	+ 1.53
1973	ns	− .0792	*	− 1.87	*	− .1882	ns	− 4.45*	ns	− .3772	ns	− 2.95	ns	− .1692	ns	− 1.47
1974	ns	− .0867	ns	− 1.90	ns	− .1346	ns	− 2.87*	ns	− .2418	ns	− 1.30	ns	− .0401	ns	− 0.16
1975	ns	− .1175	ns	− 2.04	ns	− .1921	ns	− 2.46*	ns	− .2193	ns	− 0.97	ns	− .0831	ns	− 0.34
1976	ns	− .0797	ns	− 0.48	*	− .2701	ns	− 2.76*	ns	− .3332	ns	− 1.56	ns	− .1920	ns	− 0.96
PRE	ns	− .5617	ns	− 19.07	*	− .7550	ns	− 43.34*	ns	− 1.5972	ns	− 19.53	ns	− .5886	ns	− 4.29
1978	ns	+ .0582	ns	+ 1.48	ns	+ .0222	*	− 0.18	ns	− .2623	*	− 0.85	ns	+ .2865	*	+ 2.44
1979	*	+ .1527	ns	+ 2.48*	ns	+ .2875	ns	+ 0.89	ns	+ .0660	ns	+ 0.77	ns	+ .9857	ns	+ 4.93*
1980	ns	+ .2977	ns	+ 4.10*	ns	+ .2542	ns	+ 0.42	ns	+ .0113	ns	+ 0.11	*	+ .9380	ns	+ 3.27
1981	*	+ .4504*	ns	+ 5.27*	ns	+ .6670	ns	+ 1.85	ns	+ .3139	ns	+ 1.17	*	+ 1.1299	ns	+ 3.19
1982	*	+ .5068	ns	+ 5.09*	ns	+ .7797	ns	+ 1.94	ns	+ .2413	ns	+ 0.71	ns	+ 1.1548	ns	+ 2.54
1983	*	+ .5514	ns	+ 4.31	ns	+ .3993	ns	− 0.16	ns	+ .0438	ns	+ 0.20	ns	+ .8785	ns	+ 0.84
1984	*	+ .6187	ns	+ 4.62*	ns	+ .3219	ns	− 0.12	ns	+ .0385	ns	+ 0.17	ns	+ .7045	ns	+ 0.76
POST	*	+ 2.6358	ns	+ 38.40*	ns	+ 2.7319	ns	+ 6.85	ns	+ .4526	ns	+ 3.35	ns	+ 6.0779	ns	+ 25.87

a; nc,nt = number of control and treated trees used in calculating mean values, respectively.
b; F-test of homogeneity of variance of control and treated trees.
c; Significance of differences determined by appropriate t-test, as determined in b.
d; PRE,POST = pre- and post-treatment periods, i.e., 1970-76 and 1978-84, respectively.
* Significant at the 5% level of significance.

Table 5: Annual and periodic specific volume increment (SVI) differences relative to control trees by area and tree height-area class.

	HEIGHT CLASS (m)															
	4.0				6.0											
	TREE AREA CLASS (m²)															
	4.75				2.75				4.75				6.75			
	AREA I (nc = 9)[a] (nt = 5)[a]		AREA II (nc = 7) (nt = 4)		AREA I (nc = 10) (nt = 9)		AREA II (nc = 8) (nt = 11)		AREA I (nc = 10) (nt = 9)		AREA II (nc = 8) (nt = 5)		AREA I (nc = 10) (nt = 4)		AREA II (nc = 8) (nt = 3)	
	F[b]	SVI[c] (dm³/dm²)	F	SVI (dm³/dm²)	F	SVI (dm³/dm²)	F	SVI (dm³/dm²)	F	SVI (dm³/dm²)	F	SVI (dm³/dm²)	F	SVI (dm³/dm²)	F	SVI (dm³/dm²)
1970	ns	+.0134*	*	+.0012	ns	+.0030	ns	−.0062	ns	+.0069	ns	−.0086	ns	+.0137*	ns	−.0060
1971	ns	+.0049	*	−.0031	ns	−.0017	ns	−.0080	ns	+.0058	ns	−.0056	ns	+.0084	ns	−.0043
1972	ns	+.0128*	*	−.0014	ns	−.0015	ns	−.0034	ns	+.0038	ns	−.0014	ns	+.0080	ns	+.0016
1973	ns	+.0121*	*	−.0016	ns	−.0023	*	−.0087	ns	+.0034	ns	−.0093	ns	+.0071	ns	−.0055
1974	ns	+.0094	*	−.0021	*	−.0016	ns	−.0057	ns	+.0049	ns	−.0049	ns	+.0059	ns	−.0016
1975	ns	+.0120*	ns	−.0034	ns	+.0012	ns	−.0056	ns	+.0052	ns	−.0040	ns	+.0034	ns	−.0021
1976	ns	+.0112*	ns	−.0008	ns	−.0007	ns	−.0070	ns	+.0037	ns	−.0062	ns	+.0040	ns	−.0045
PRE[d]	ns	+.1315*	*	−.0123	ns	−.0106	ns	−.0888	ns	+.0409	ns	−.0637	ns	+.0749	ns	−.0330
1978	ns	+.0074	*	+.0035	ns	+.0025	ns	.0000	ns	+.0064	ns	−.0040	ns	+.0065	ns	+.0060
1979	ns	+.0112*	*	+.0060	ns	+.0057	ns	+.0042	ns	+.0097*	ns	+.0018	ns	+.0112	ns	+.0162*
1980	ns	+.0089*	ns	+.0102*	ns	+.0065*	ns	+.0030	ns	+.0098*	*	.0000	ns	+.0128*	*	+.0127
1981	ns	+.0023	ns	+.0137*	ns	+.0026	*	+.0088*	ns	+.0049	*	+.0043	ns	+.0058	*	+.0140
1982	ns	+.0032	ns	+.0141*	ns	+.0051	ns	+.0095	*	+.0072	ns	+.0027	*	+.0123	*	+.0128
1983	ns	+.0062	ns	+.0135	ns	+.0049	ns	+.0027	ns	+.0092	ns	−.0006	ns	+.0252	*	+.0075
1984	ns	+.0086	ns	+.0144*	ns	+.0119	ns	+.0023	ns	+.0116	ns	+.0002	ns	+.0284	*	+.0063
POST[d]	ns	+.0551	ns	+.0994*	ns	+.0475	ns	+.0376	ns	+.0692	ns	+.0066	ns	+.1248	*	+.0977

a; nc,nt = number of control and treated trees used in calculating mean values, respectively.
b; F-test for homogeneity of variance of control and treated trees.
c; Significance of differences determined by appropriate t-test, as determined in b.
d; PRE,POST = pre- and post-treatment periods, i.e., 1970-76 and 1978-84, respectively.
* Significant at the 5% level of significance.

Table 6: Periodic live crown ratio, form factor and specific gravity response differences relative to control trees by area and tree height-area class.

PARAMETER	AREA I															
	HEIGHT CLASS (m)															
	4.0				6.0											
	TREE AREA CLASS (m²)															
	4.75				2.75				4.75				6.75			
	(nc = 9)[a]			(nt = 5)[a]	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 9)	(nc = 10)			(nt = 4)
	F[b]	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.[c]	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.
LCR[d]	ns	.3861	.5363	+ *	ns	.4290	.4505	ns	ns	.4290	.5910	+ *	ns	.4290	.5729	+ *
FF[e]	ns	.3861	.3917	ns	ns	.3508	.3674	ns	ns	.3508	.3466	ns	ns	.3508	.3489	ns
SG[f]	ns	.3810	.3778	ns	ns	.3887	.3824	ns	ns	.3887	.3706	ns	ns	.3887	.3665	ns

PARAMETER	AREA II															
	HEIGHT CLASS (m)															
	4.0				6.0											
	TREE AREA CLASS (m²)															
	4.75				2.75				4.75				6.75			
	(nc = 7)			(nt = 4)	(nc = 8)			(nt = 11)	(nc = 8)			(nt = 5)	(nc = 8)			(nt = 3)
	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.	F	CONTROL (mean)	TREATED (mean)	SIGN. OF DIFF.
LCR	ns	.4422	.5895	ns	ns	.5457	.5863	ns	ns	.5457	.5057	ns	ns	.5457	.5361	ns
FF	ns	.3361	.3399	ns	ns	.3439	.3428	ns	ns	.3439	.3945	ns	ns	.3439	.3787	ns
SG	ns	.3986	.4110	ns	ns	.3876	.4277	ns	ns	.3875	.4042	ns	ns	.3876	.3916	ns

a; nc,nt = number of control and treated trees used in calculating mean values, respectively.
b; F-test for homogeneity of variance of control and treated trees.
c; Significance of differences determined by appropriate t-test, as determined in b.
d; LCR = live crown ratio (%).
e; FF = cylindrical form factor.
f; SG = specific gravity for post-treatment period (i.e., 1978-84) at breast height.
* Significant at the 5% level of significance.

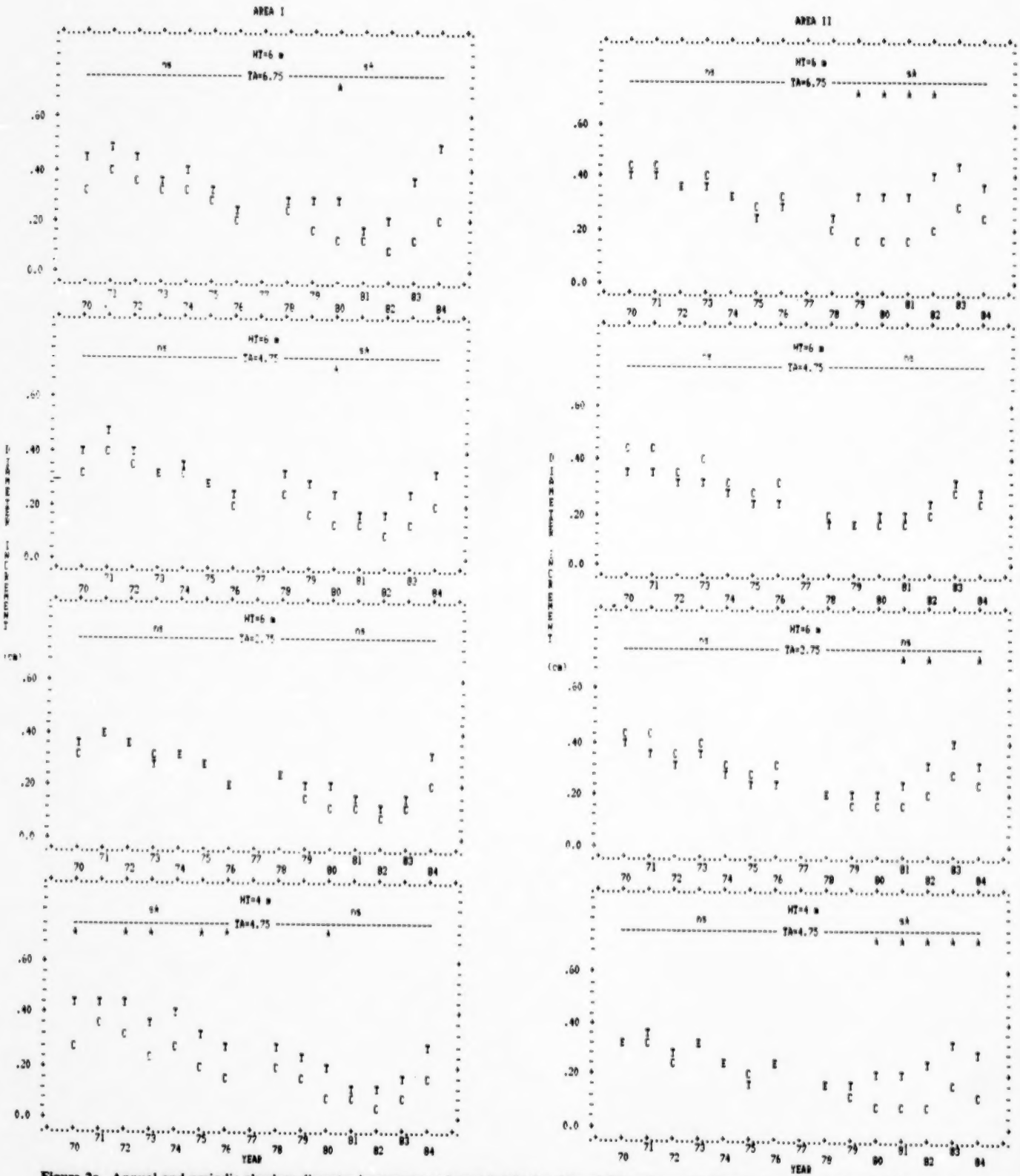


Figure 2a. Annual and periodic absolute diameter increments at breast height for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); E = points of equivalence; Significance of annual and periodic increment differences indicated below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly different at the 5% level.

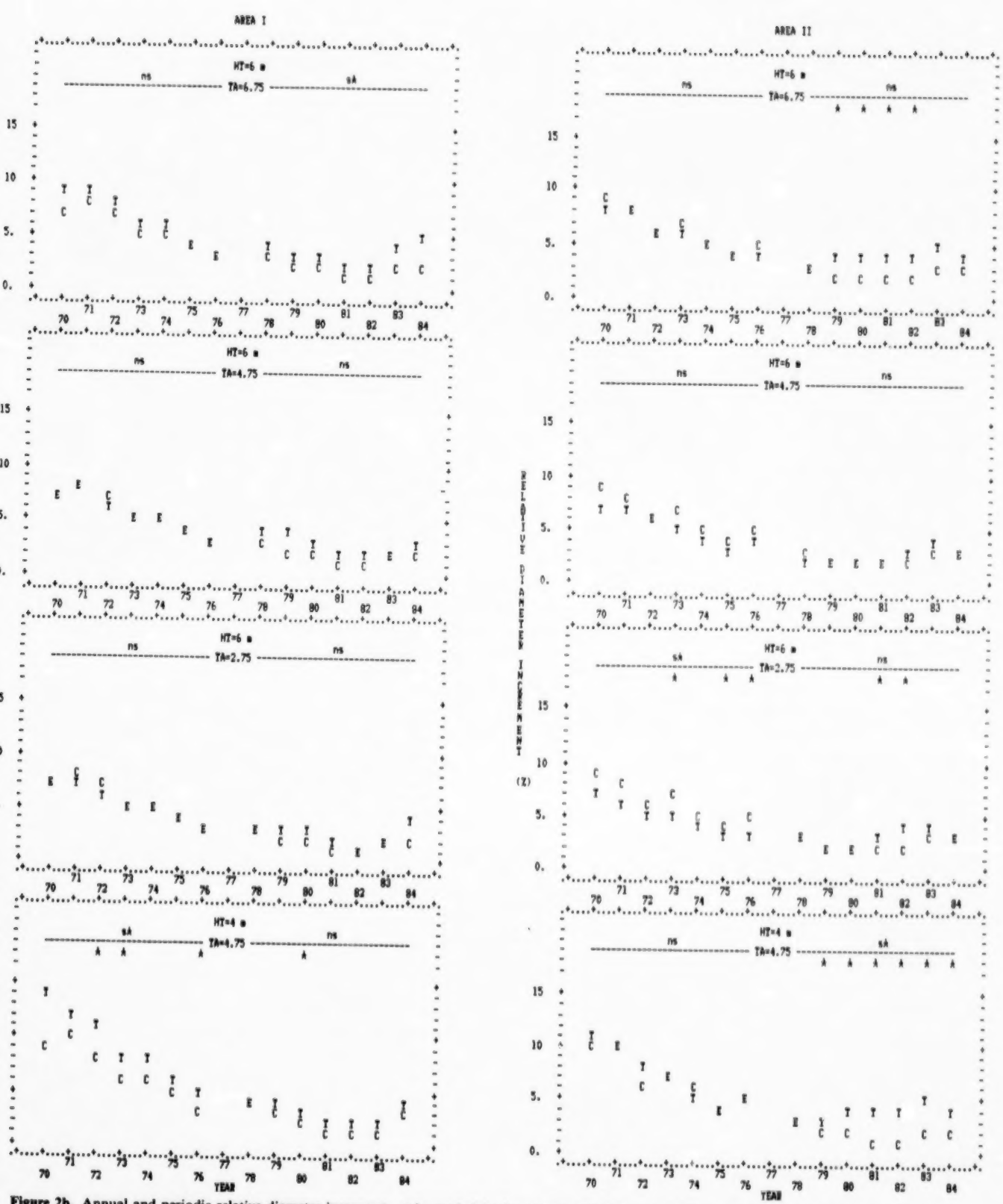


Figure 2b. Annual and periodic relative diameter increments at breast height for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); E = points of equivalence; Significance of annual and periodic increment differences indicated below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly different at the 5% level.

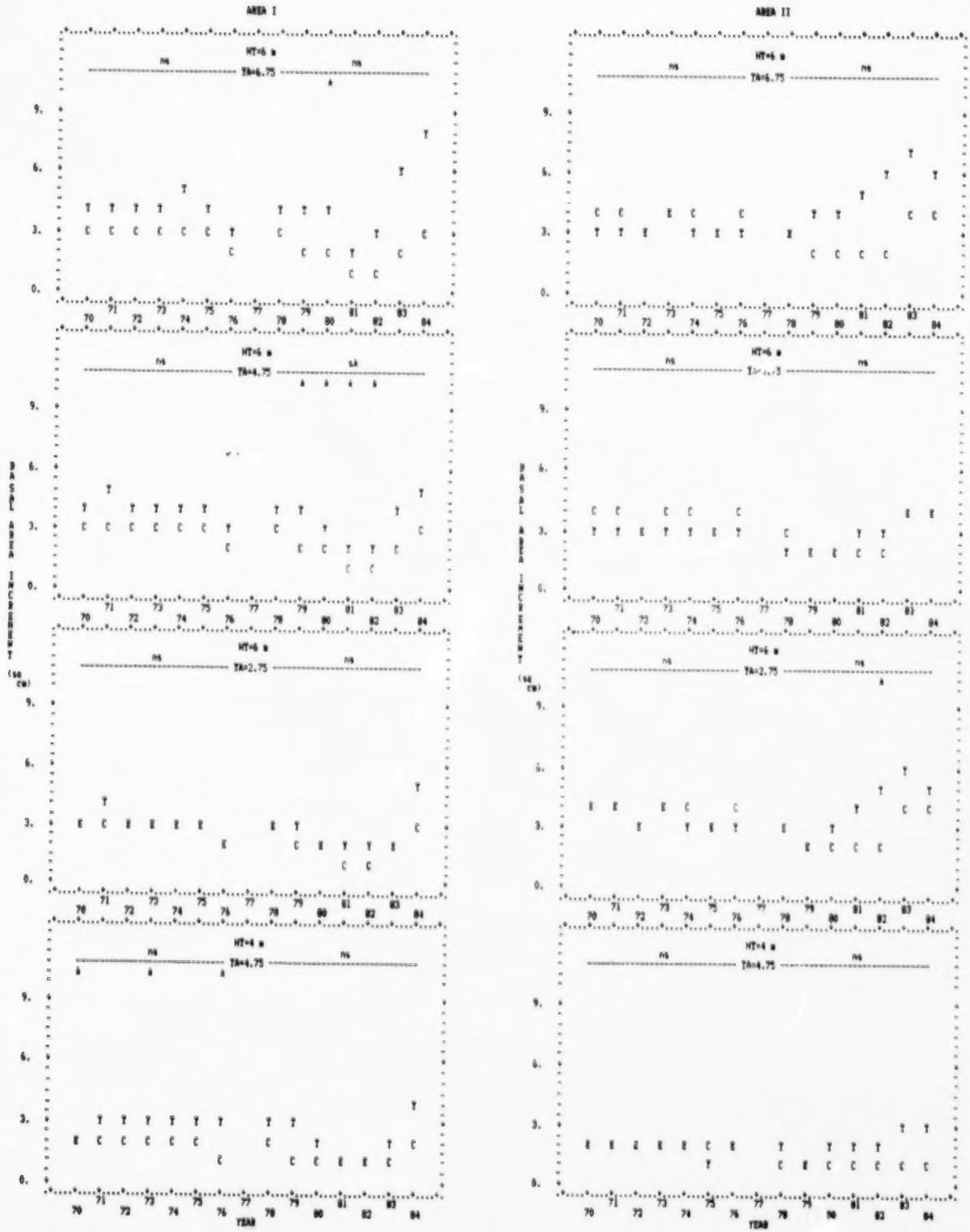


Figure 3a. Annual and periodic absolute basal area increments at breast height for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); E = points of equivalence; Significance of annual and periodic increment differences indicated below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly different at the 5% level.

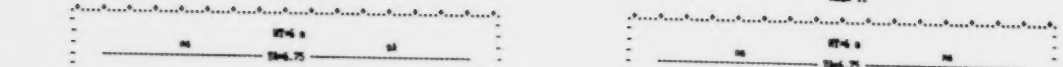


Figure 3b. Annual and periodic relative basal area increments at breast height for thinned (T) and control (C) trees by area and tree height-area c
For each graph: HT = height; TA = tree area (m²); E = points of equivalence; Significance of annual and periodic increment differences ind
ed below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly differe
the 5% level.

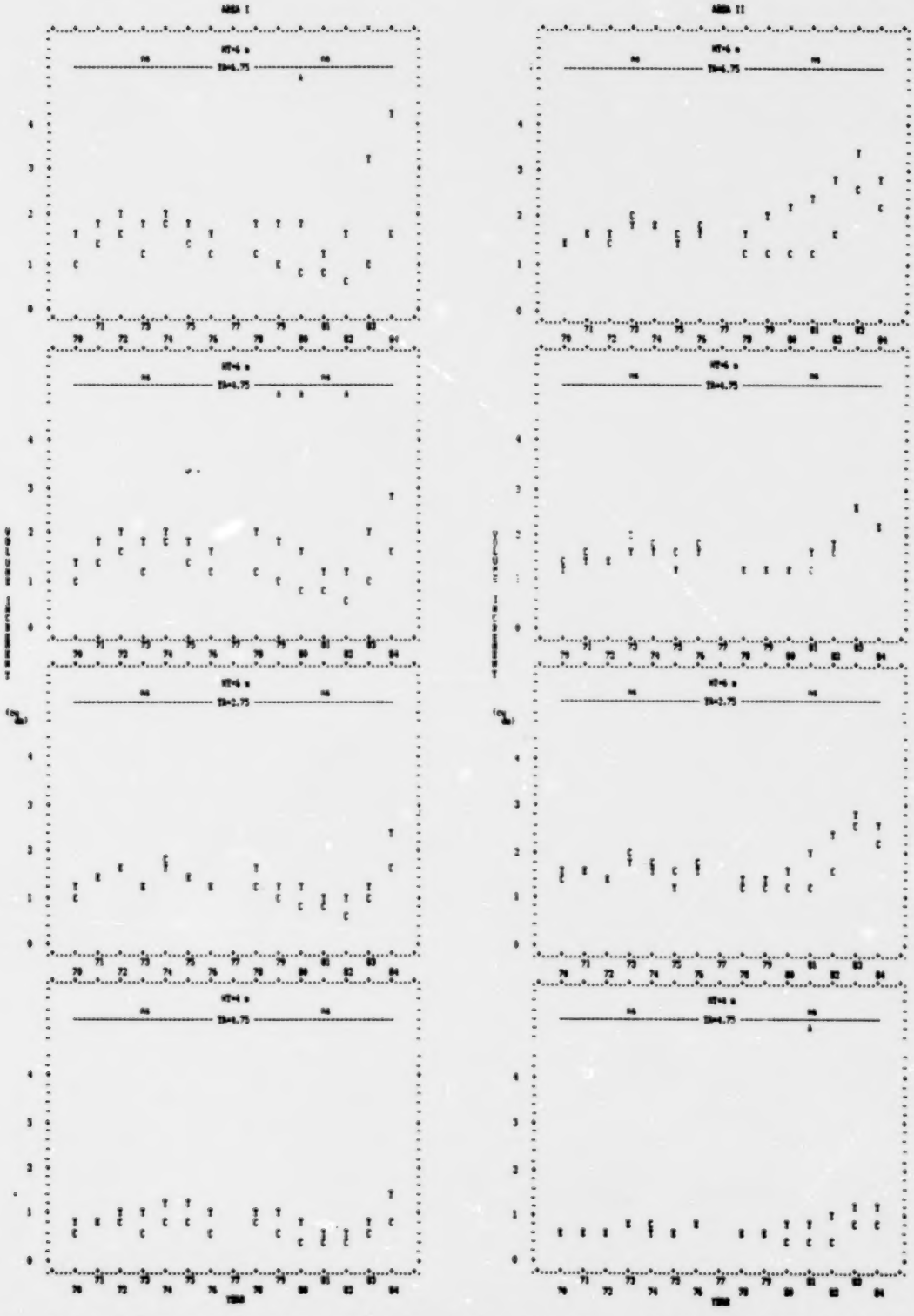


Figure 4a. Annual and periodic absolute volume increments for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); E = points of equivalence; Significance of annual and periodic increment differences indicated below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly different at the 5% level.

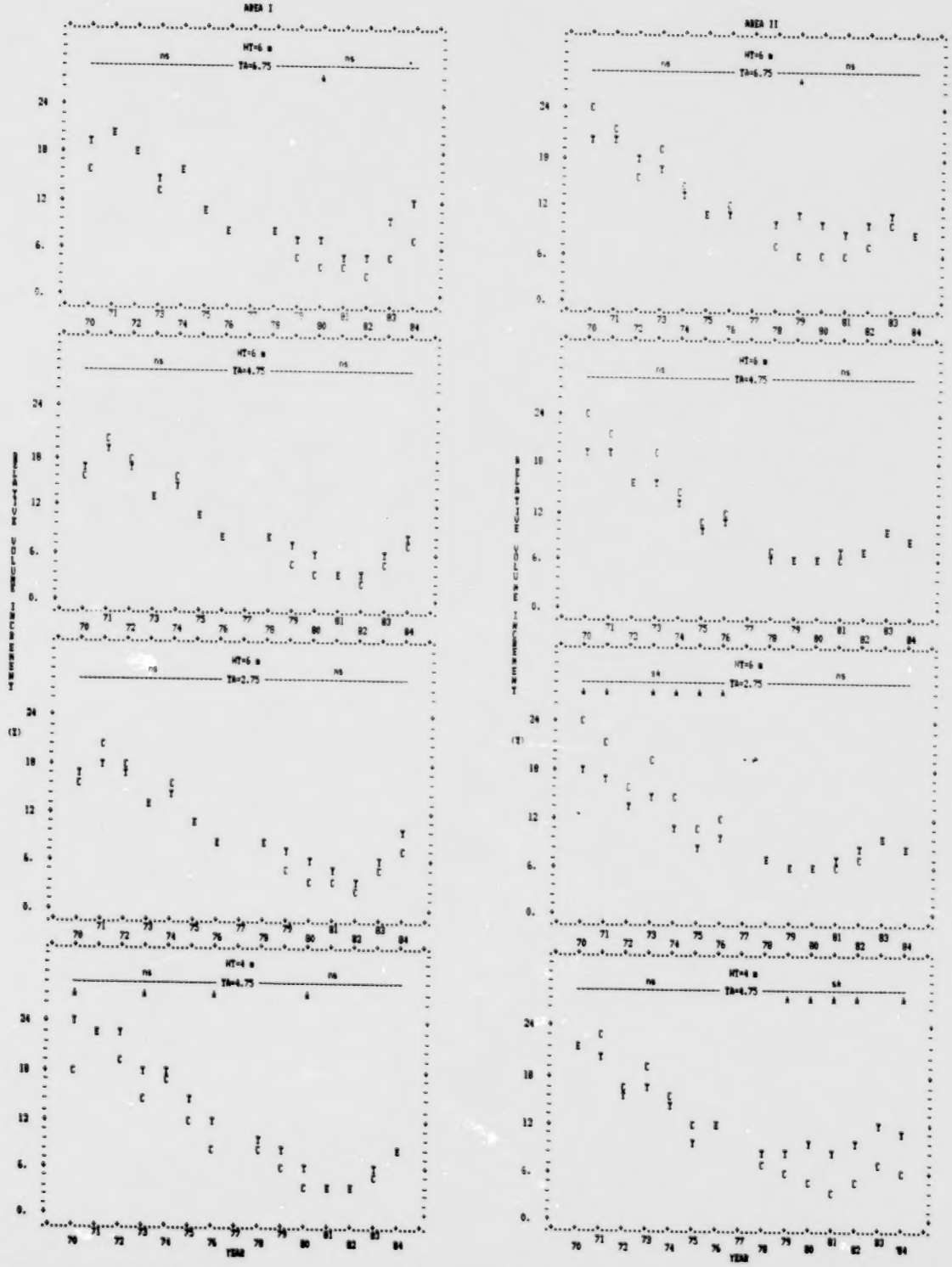


Figure 4b. Annual and periodic relative volume increments for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); E = points of equivalence; Significance of annual and periodic increment differences indicated below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly different at the 5% level.

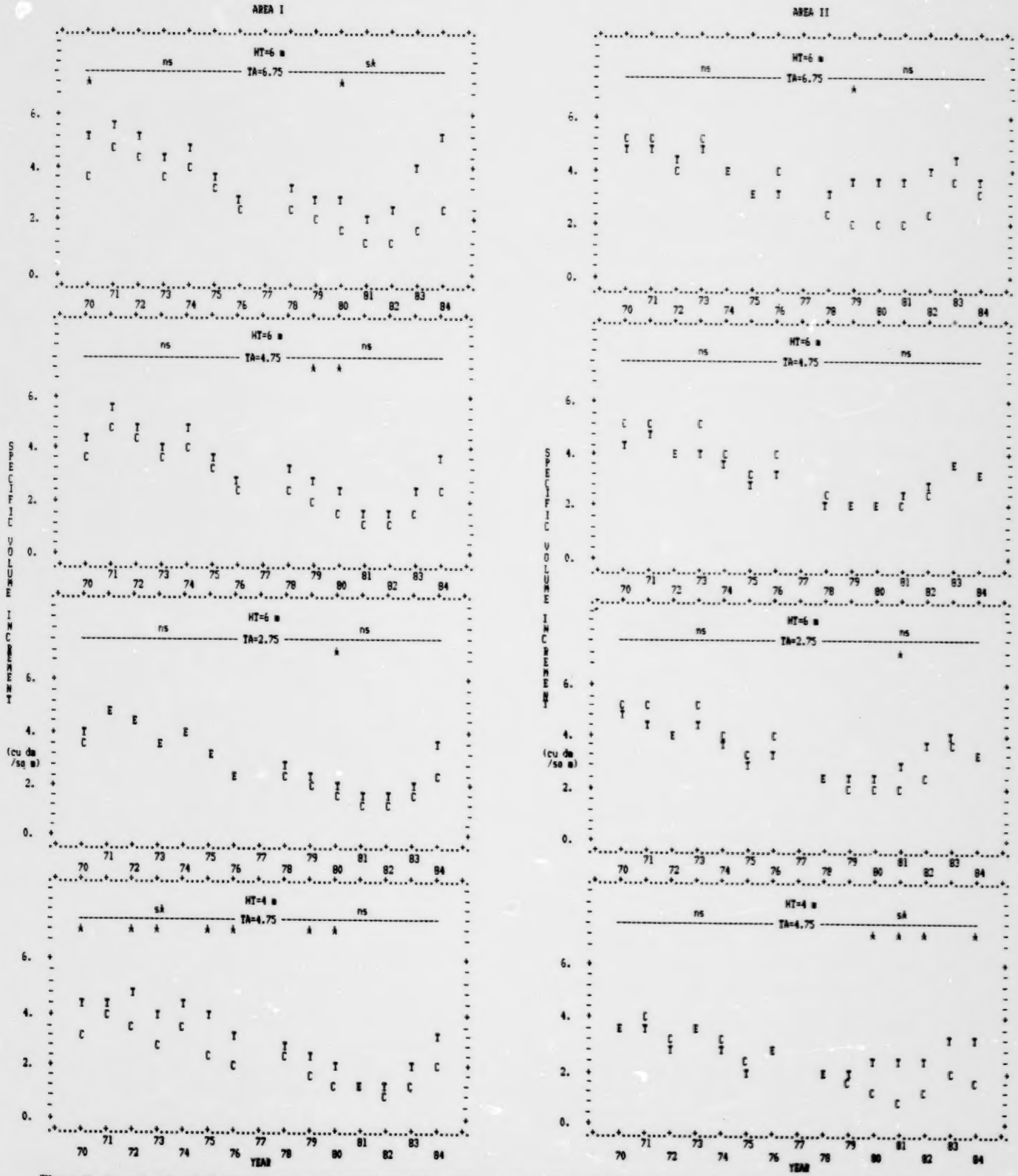


Figure 5. Annual and periodic specific volume increments for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); E = points of equivalence; Significance of annual and periodic increment differences indicated below and above the dash line, respectively. Where ns = non-significantly different at the 5% level and * or s* = significantly different at the 5% level.

Figure 6. Post-treatment, absolute and relative, periodic diameter, basal area and volume increments and specific volume increments for thinned (T) and control (C) trees by area and tree height-area class. For each graph: HT = height; TA = tree area (m^2); I or II = Areas I and II, respectively. Significance of increment differences are indicated above the dash line, where s* = significantly different at the 5% level.

Discussion

Results indicated that absolute and relative diameter, basal area and volume and specific volume increments were greater in the thinned portions than in the unthinned portions of both areas within seven years of treatment. Live crown ratios were greater in the treated portions than in the untreated portions eight years after treatment. There were no consistent difference in cylindrical form factor or specific gravity between thinned or unthinned portions eight years after treatment. However only a small number of these increases could be statistically attributed to thinning, due partially to the inversely related effects of thinning and spruce budworm defoliation.

Radial Growth

Thinning stimulates radial growth at the base of the stem (Larson 1963; Kozlowski 1971), whereas spruce budworm defoliation causes a reduction in growth (Myers 1963; Blais 1964). Consequently, diameter, basal area, volume increments and stem taper increase due to thinning but decrease due to defoliation. Reduction or destruction of the terminal leader by the spruce budworm can also result in a volume reduction (Schooley 1980) and an increase in the cylindrical form factor. The general non-significant effect of thinning on diameter, basal area and volume growth, and form observed in this study are indicative of these inversely related effects. The two tree height-area classes that showed a significant overall response, 4 m-4.75 m^2 and 6 m-6.75 m^2 both at Area II, appear to have responded differently to the same level of defoliation. Piene (1980) found a 31% difference in the volume growth of balsam fir (*Abies balsamea* L.) trees that were under similar defoliation pressures.

Specific Volume Increment

Specific volume increment is the ratio of the volume of xylem tissue produced relative to the cambial surface area from which it is derived (Duff and Nolan 1957). Piene (1981) suggests that this ratio is a sensitive measure of the supply-demand relationship of raw materials. For example, a decrease in specific volume increment indicates that the demand for raw materials was greater than the supply. Thus thinning would increase and defoliation would decrease specific volume increment. These counterbalancing influences are reflected by the overall non-significant result observed in this study in terms of specific volume increment. However the two classes that did significantly respond to thinning, 6 m-6.75 m^2 at Area I and 4 m-4.75 m^2 at Area II, may have been physiologically superior to the other classes at the time of defoliation.

Live Crown Ratio

Trees within recently thinned stands exhibit a reduction in the rate of crown recession and an increase in crown width, leaf growth, branch size and production of branch wood (Kozlowski 1971). Whereas trees defoliated by spruce budworm show reduced terminal leader and branch terminal lengths (Schooley 1980). Thus live crown ratios would increase after thinning but decrease after defoliation. Live crown ratios of trees within Area I generally increased after thinning however the trees in Area II did not. This comparison between treated and untreated trees occurred eight years after treatment hence the inverse effects of spruce budworm defoliation are partially eliminated within Area I over time whereas trees within Area II have yet to overcome these effects.

Specific Gravity

Since in many conifers the specific gravity of the latewood zone is more than twice that of the earlywood zone any increase in the proportion of earlywood results in a decrease in whole-ring specific gravity (Elliot 1970). Conditions favourable to vegetative growth occur earlier in thinned stands than in unthinned stands (Piene 1978) with the result that the proportion of earlywood increases after thinning thus reducing whole-ring specific gravity. Insect defoliation during the period of earlywood formation would increase whole-ring specific gravity. Specific gravity within black spruce stems is significantly and highly influenced by heritability factors (Khalil 1985). Thus while it appears that the non-significant thinning effect observed in this study may be due to the thinning effect being reduced by the effects of budworm defoliation, there is possibly a dominant genotypic influence which minimized environmental effects. This was not determined for the stands in question.

Initiation, Duration and Magnitude of Response

Differences in initial size conditions reduce the number and quality of the inferences drawn when using absolute increments. However, using relative increments eliminates the effects of these differences improving the interpretation of the responses. Thus only relative responses are considered in discussing the the initiation, duration and magnitude of the thinning response.

Generally, the results of this study suggest that in-

itiation, duration and magnitude of response is related to the initial tree height-area class. Annual relative diameter, basal area and volume, and specific volume responses of trees within the 4 m-4.75 m^2 height-area class started earlier and were continuous and greater in magnitude than those of the dominant three classes. Codominant or intermediate trees often exhibited proportionally greater responses than dominant trees (Larson 1963). The duration and magnitude of responses of dominant trees increased as available area increased. Responses of dominant trees within the 2.75 and 4.75 m^2 classes were either nil or short in duration and low in magnitude. Trees within the 6.75 m^2 classes illustrated proportionally greater responses than those in the other two dominant area classes.

As was expected relative diameter, basal area, and volume responses were directly proportional on both an annual and periodic basis.

Overall growth trends of trees within both areas from 1970 to 1984 illustrate a consistent pattern. Relative diameter, basal area, volume and specific volume increments maximized during the period from 1970 to 1972, declined continuously during the period from 1973 to 1981 or 1982, and then increased in 1983 and 1984. The initial decline in increments from about 1973 to 1976 may have resulted from increased intraspecific competition and defoliation. Likewise, from 1978 to 1982, declines in increment within the unthinned portions of each area may be attributed to increasing intraspecific competition and spruce budworm defoliation. Within the thinned portions declines are largely due to defoliation. This inference is partially supported by the general increases observed in 1983 within both areas and in 1984 within Area I, irrespective of treatment. Annual decreases in 1984 within Area II for both unthinned and thinned portions of the stands suggest a localized impact, possibly due to hemlock looper (*Lambdina fiscellaria fiscellaria* (Guen.)) defoliation.

Summary

The results of this study provide the forest manager with information on initial response of partially defoliated black spruce trees to precommercial thinning operations. Specifically, positive increases in absolute and relative diameter, basal area and volume, and specific volume increments were evident in all tree height-area classes within seven years of thinning and live crown ratios increased eight years after treatment. However, only a small number of these increases could be statistically attributed to thinning, partially due to the extraneous effects of spruce budworm defoliation. Considering that (i) the crown occupancy levels (mean crown area/tree area ratio) eight years after treatment of 44%, 72%, 50% and 35%, for the 4 m-4.75 m^2, 6 m-2.75, 4.75 and 6.75 m^2 tree height-area classes, respectively, and (ii) the collapsed spruce budworm populations (Raske 1985) and thus cessation of defoliation effects, future gains due to thinning could be substantial.

The results presented in this study reflect actual conditions within the black spruce stands studied. These results may be applicable to other black spruce stands thinned during the spruce budworm outbreak, however this would have to be confirmed through additional research. Inferences drawn from the results suggest that unless protection programs are implemented during spruce budworm outbreaks only minimal initial gains will be realized from thinning black spruce stands.

Literature Cited

Ballard, T.M.; Majid, N. 1985. Use of pretreatment increment data in evaluating tree growth response to fertilization. Can. J. For. Res. 15:18-22.

Black, C.A. (ed) 1965. Methods of Soil Analysis. Part 2. American Society of Agronomy. Madison, Wis. 770 p.

Blais, J.R. 1957. Some relationships of the spruce budworm to black spruce. For. Chron. 33:364-372.

_____ 1964. Account of a recent spruce budworm outbreak in the Laurentide Park reigon of Quebec and measures for reducing damage in future outbreaks. For. Chron. 40:313-323.

Bryant, D.G.; Raske, A.G. 1976. Impact of the spruce budworm on some major forest types of Newfoundland. I. Plot establishment and methods. Can. For. Serv., Nfld. For. Res. Cent., St. John's, Nfld. File Rep. 15-6. 26 p.

Canadian Soil Survey Committee. 1978. The Canadian system of soil classification. Can. Dep. of Agric., Res. Branch, Ottawa, Ont. Publ. 1646. 164 p.

Crown, M.; Quenet, R.V.; Layton, C. 1977. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawinigan lake. Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C. Inf. Rep BC-X-152. 36 p.

Damman, A.W.H. 1964. Some forest types of central Newfoundland and their relation to environmental factors. For. Sci. Monogr. 8:1-62.

_____ 1976. Plant distribution in Newfoundland especially in relation summer temperatures measured with the sucrose inversion method. Can. J. Bot. 54:1561-1585.

_____ 1983. An ecological subdivision of the Island of Newfoundland. Pages 163-206 in G.R. South, ed. Biogeography and Ecology of the Island of Newfoundland. Monogr. Biol. 48.

Duff, G.H.; Nolan, J. 1957. Growth and morphogenesis in the Canadian forest species. II. Specific increments and their relation to the quantity and activity of growth in Pinus resinosa Ait. Can. J. Bot. 35:527-572.

Elliot, G.K. 1970. Wood density in conifers. Comm. For. Bureau., Tech. Comm. No. 8. 44 p.

Hayden, D. 1986. Newfoundland's forests and forest industry: statistical information 1985 edition. Can. For. Serv., Nfld. For. Cent., St. John's, Nfld. Inf. Rep. N-X-233. 47 p.

Husch, B.; Miller, C.I.; Beers, T.W. 1982. Forest mensuration. 3rd ed. Ronald Press Co., New York, N.Y. 402 p.

Khalil, M.A.K. 1985. Genetics of wood characters of black spruce (Picea mariana (Mill.) B.S.P.) in Newfoundland, Canada. Silvae Genet. 34:221-230.

Kozlowski, T.T. 1971. Growth and Development of Trees, Vol. II. New York, N.Y. 514 p.

Larson, P.R. 1963. Stem form development in forest trees. For. Sci. Monogr. 5:1-41.

Myers, C.A. 1963. Vertical distribution of annual increment in thinned ponderosa pine. For. Sci. 9:394-404.

Orr, H.K. 1968. Soil-moisture trends after thinning and clearcutting in a second-growth Ponderosa pine stand in the Black Hills. U.S. For. Serv., Res. Note RM-99. 8 p.

Otvos, I.S.; Moody, B.M. 1978. The spruce budworm in Newfoundland: History, status and control. Can. For. Serv., Nfld. For. Res. Cent., St. John's, Nfld. Inf. Rep. N-X-150. 76 p.

Otvo, I.S.; Clarke. L.J.; Durling, D.S. 1979. A history of recorded eastern hemlock looper outbreaks in Newfoundland. Can. For. Serv., Nfld. For. Res. Cent., St. John's, Nfld. Inf. Rep. N-X-179. 46 p.

Pielou, E.C. 1959. The use of point to plant distances in the study of the pattern of plant populations. J. Ecol. 47:607-613.

Piene, H. 1978. Effects of increased spacing on carbon mineralization rates and temperature in a stand of young balsam fir. Can. J. For. Res. 8:398-406.

_____ 1980. Effects of insect defoliation on growth and foliar nutrients of young balsam fir. For. Sci. 26:665-673.

_____ 1981. Early growth response to operational spacing in young balsam fir stands on the Cape Breton Highlands, Nova Scotia. Can. For. Serv., Marit. For. Res. Cent., Fredericton, N.B. Inf. Rep. M-X-125. 29 p.

Raske, A.G. 1985. Collapsing budworm populations. Pages 141-142 in C.J. Sanders, R.W. Stark, E.J. Mullins, and J. Murphy, eds. Recent Advances in Spruce Budworm Research. Proc. CANUSA Spruce Budworms Research Symp., Bangor, M.E. Sept. 16-20, 1984.

Raske, A.G.; Moody, B.H. 1981. Commercial Fibre Production. Pages 37-47 in J. Hudak and A.G. Raske, eds. Review of the Spruce Budworm Outbreak in Newfoundland—Its Control and Forest Management Implications. Can. For. Serv., Nfld. For. Res. Cent., St. John's, Nfld. Inf. Rep. N-X-205. 208 p.

Raske, A.G.; Rowe, J.D. 1976. Impact of the spruce budworm on some major forest types of Newfoundland. II. Plot location. Can. For. Serv., Nfld. For. Res. Cent., St. John's, Nfld. File Rep.: Study 15-6. 48 p.

Raske, A.G.; Sutton, W.J. 1986. Decline and mortality of black spruce caused by spruce budworm defoliation and secondary organisms. Can. For. Serv., Nfld. For. Cent., St. John's, Nfld. Inf. Rep. N-X-236. 29 p.

Rowe, J.S. 1972. Forest regions of Canada. Can. Dep. Environ., Can. For. Serv., Publ. No. 1300. 172 p.

Schooley, H.O. 1980. Damage to black spruce cone crops by the spruce budworm. Can. For Serv., Nfld. For. Res. Cent., St. John's, Nfld. Inf. Rep. N-X-187. 15 p.

Smith, D.M. 1962. The practice of silviculture. John Wiley and Sons Inc., New York, N.Y. 578 p.

TAPPI (Technical Association of the Pulp and Paper Industry). 1953. Specific gravity (density) and moisture content of pulpwood. Tech. Ass. of Pulp and Pap. Ind., Offic. Stand. No. T18 OS-53. 4 p.

Weetman, G.F.; Roberge, M.R.; Meng, C.H. 1980. Black spruce: 15-growth and microbiological responses to thinning and fertilization. Can. J. For. Res. 10:502-509.